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Sustainability examination of the short rotation coppices

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SUMMARY

The main aim of the present article is to determine the economical and environmental sustainability of short rotation coppice (SRC) plantations of poplar, willow and black locust. For all three species an intensive and extensive production method was set up with their corresponding cost levels. Using the extremes of the production costs and values, four scenarios were set up with their corresponding land characteristics.

As a consequence of the annual demand for expenditure the biomass is called as a conditionally renewable energy resource, its production means both financial and an energetic risk due to the uncertainties. With the highest utilization of the biological potential, quick return and economically sustainable farming can be achieved in a good quality land, primarily with the use of intensive production technology. These conditions can not be fulfilled in those low quality land where are these kinds of plantations are intended to establish. Our energetic calculations also reflect the uncertainties around the energetic use of biomass.

The energetic metrics, the difference and the ratio of energy output and input can be estimated in specific cases but no general conclusions can be drawn for the energy production of SRC primer biomass sector as a whole.

From the model it was determined in which scenarios economically sustainable biomass production is possible and in which scenarios environmental sustainability is achieved. It can be stated that the SRC energy plantations can meet the criteria of the economic or environmental sustainability, but not both of them at the same time.

Keywords: renewable energy source, biomass use, payback time, energy balance

INTRODUCTION

In today's fast world, the main aim of mankind is to increase competitiveness, while disregarding our eternal dependency on the nature and the limits of the Earth's carrying capacity. As energy is the basis for the economy and production, the ecopolitical importance of renewable energy resources is unquestionable. Sustainability cannot be achieved without renewable resources, and besides that, renewables play a key role in fighting anthropogenic climate change, too.

Considering the endowments of Hungary, among renewable resources biomass has an unused potential that, if exploited, may partly replace fossil energy. This could mainly be accomplished by sustainable biomass production on low quality lands unfit for agricultural production.

Our research focuses on the economical and environmental sustainability of biomass as an energy source. The main objects and aims of the publication are to explore the environmental and economical criteria of efficient production using energy plantations. Using observations of production and a model based on domestic research results we are trying to find out whether short rotation coppice (SRC) plantations can meet the requirements of either economical or environmental sustainability or both at the same time.

LITERATURE OVERVIEW

Biomass is the 4th most widely used energy resource and the leading renewable energy resource in the world, despite the fact that it has the lowest theoretical potential among renewables. Biomass is a collective term; primer biomass is comprised of main and by-products of plant origin to include short rotation coppice (SRC) plantations as well (*Bohoczky* 2005). The utilization methods and energy balance are strongly influenced by the conversion ways of different energy demands. The heat generation efficiency of biomass is only slightly below fossil fuels. The efficiency of electricity generation is 30% for wood, 25% for agricultural by-products and 44% for black coal. The most efficient electricity generation can be achieved by burning natural gas (52.5%) as opposed to burning biogas (42%) (*Büki* 2007). The efficiency and economy of electricity generation can be improved by the utilization of residual heat (*Barta-Juhász* 2014).

Due to their different demands, the three species are supplemental and not competitive to each other. Taking advantage of the characteristics of the three species, more lands can be used for SRC plantations.

Based on the practical experiences, the most current research focuses on improving the efficiency of planting and maintaining SRC plantations. Besides that, there are also studies on the environmental effects (*Porsö and Hansson* 2014, *Dimitriou and Mola-Yudego* 2017), energy balance (*Dillen et al.* 2013), and economy of energy plantations (*Pereira et al.* 2016). In Hungary, black locust occupies 24% of forested areas (*Rédei et al.* 2017). In other European countries, besides the energetic use of black locust (*Stolarski* 2017), its ecological effect as an invasive species is also studied (*Lazzaro et al.* 2017).

Besides the energetic use of SRC species, there are studies on their other use as well. Promising results were obtained on the recultivation of degraded lands, the phytoremediation of soils contaminated with pesticides and heavy metals (*Lafleur et al.* 2016, *Forbes* et al. 2017), the phytoextraction potential of clones, genotypes and their possible bacterial communities (*Algreen et al.* 2013, *Kacálková et al.* 2015), and the positive effects of bacterial communities and mycorrhizae on extraction and biomass production (*Fillion et al.* 2011; *Janssen et al.* 2015).

There are several directions and conceptions about the energetic use of SRC's with several arguments and their rebuttals; no widely accepted professional consensus exists (*Gyulai* 2010). There is an uncertainty regarding the life-cycle based energy balance of biomass based energy production (*NFFT* 2011). Concerning this problem, *Egri* (2014) recommends measuring the emission of power plants and analyzing the effect of the harmful emissions from transportation on the carbon dioxide balance. By a complex approach with a multi-factor comparative method *Takács and Takács-György* (2013) created an environmental-economic-social sustainability model. The ranking decision making alternatives during the establishment a biomass power plant by the examination of the relations of the logistics costs, energy payback, CO_2 emission and economic return factors can be determined. *Tégla et al.* (2012) emphasize the importance of the role of cooperation as a factor in biomass production through which the environmental impact can decrease and the profitability also can be improved in the same time. According to Barótfi, the longest desirable transportation distance for sustainable biomass electricity generation is 20 to 40 km (*Barótfi* 2009 cit. *NFFT* 2011, 63). A background study for the Renewable Energy Action Plan of Hungary by Pálvölgyi concludes that among conditionally renewable energy resources, SRC's are disadvantageous and firewood is unfavourable from an environmental point of view. Still, firewood makes up the majority of renewable power generation in Hungary. This fact raises the issue that the measures for achieving the goals of environmental sustainability may result greater harms than advantages for the nature, or at least the expected advantage of renewables over fossil fuels is lost.

In Hungary, the Forest Research Institute (ERTI) started a study on the State Farm of Lajtahanság. The research focused on the time of optimal rotation, and the effect of spacing and fertilization (*Sutyera* 2014). A research consortium led by Gyuricza conducted studies on the recultivation of lands contaminated by the alumina sludge spill with energy plantations (*Gyuricza et al.* 2011). *Kovács* (2010) underlines the role of energy plantations in the protection and recultivation of landscapes.

The Renewable Energy Action Plan of Hungary planned energy plantations primarily on lands unfit for agricultural production (below 17 Gold Crown value, exposed to inland inundations and floods), to involve 200,000 hectares (*NFM* 2011).

Summarizing the development of biomass utilization is not a definite success story. Paradoxically, several environmental concerns and uncertainties arose about their use, particularly about the production, transportation and utilization in power plants.

MATERIAL AND METHODS

The calculations examined the profitability of planting and maintaining an SRC plantation of average conditions using only own resources. Average conditions mean that the conditions of the plantation do not make any further special works necessary above the production procedures detailed. In the model the biomass is sold directly to a power plant. The financial values presented are net values.

For our deterministic model the production technology and achievable average yields that are crucial for calculating production costs and income were based on literature sources.

In our scenario analysis in order to determine typical yield to cost relations, four scenarios with three transportation distances were set up for each tree species (willow, poplar, black locust) by pairing cash flow variations and land conditions. Intensive and extensive production methods were determined using the extremities of production values and costs.

SRC plantations involve production periods longer than a year. Thus, economical analyses also refer to one production cycle or to a determined time period. In the financial calculations of the economical model, the accumulated results of 15 years were calculated using the different yield and cost data of scenarios, thus presenting the different payback periods and profitability of scenarios.

The effect of the time value of money on the investment was evaluated using dynamic metrics. The starting cash flow at the beginning phase of the investment and the net cash inflows of each following year were totaled using the Net Present Value (NPV) formula.

Financial values were calculated using an expected return of 7% and zero residual value at the end of the 15 years production period. The expected return of 7% derives from the expected inflation and the profitability of alternative investments.

In addition to the cash flow analysis of the scenarios, the environmental sustainability of the production was determined using an energetic approach. The results of the economical model calculations are the basis for my conclusions that present a novel exploration of the contexts of economical and environmental sustainability.

Costs of production procedures were determined using the data of the National Agricultural Research and Innovation Centre Institute of Agricultural Engineering (NAIK-MGI). Costs were calculated as contract work, with approximately 20% profit above cost price. The database contained no data about harvest which requires special machinery, therefore harvest costs were determined using the practical experiences of experts working in this branch.

Lowest and highest production yields were calculated for all three species using literature data. Yields were expressed in the weight of absolute dry wood (oven dried tons, odt):

- Poplar 8.7-23 odt/ha/year
- Willow 10-24 odt/ha/year
- Black locust 6-20 odt/ha/year

For purchase price based on the contract price of the biomass power plant in Pécs, Hungary (20,000 HUF/odt) was used.

RESULTS

Protection against game damage with game fence

Due to the long production cycles, wild animals can destroy the yields of several years which may postpone return with years. The most effective protection is a game fence around the plantation. The installation cost of a game fence is at the same magnitude as the plantation costs. Besides the technical and quality characteristics of the materials used, the installation cost of the fence also depends on the land attributes, especially size and shape.

Assuming that the acceptable value of the fence installation cost is below 50% of the total plantation costs, it can be concluded that the justification of the game fence depends significantly on the level of plantation costs. Within the financial circumstances of my model, a game fence is justified above 5 or even 20-30 hectares. In our opinion, a general rule cannot be set up in this matter. Fence installation costs are not included in the current model, however, we consider it important to cover this cost element as well.

Cumulative profit of the SRC species

To the four scenarios established in the model production and land characteristics can be associated with typical yield-cost relations:

Scenario 1 (S1): Production cost (low) + production value (high). With high average yields and low cost, extensive production is typical on good quality lands where outstanding outputs can be achieved with relatively low inputs.

Scenario 2 (S2): Production cost (high) + production value (low). In this scenario low yields are coupled with high inputs. This can occur on adequate quality lands with intensive production where due to unfavourable conditions (weather, game damage) lower yields were achieved in the current production cycle. Another possible reason is that the extra inputs of intensive production cannot be exploited to the expected levels. The insufficient efficiency may be a result of the production technology or unfavourable conditions on low quality lands (e.g. high water level) preventing the culture from exploiting the inputs to the desired level. This is the worst scenario.

Scenario 3 (S3): Production cost (low) + production value (low). Extensive production with low yields. This scenario is typical on low quality lands where unfavourable land conditions are not improved to a more optimal level by extra inputs.

Scenario 4 (S4): Production cost (high) + production value (high). This scenario is typical to intensive production that achieves high yields with high cost levels with a relatively high degree of reliability. This production type is most effective on good quality lands but may be successful on some lower quality lands, too.

The payback periods

The low energy density of woodchip results in high transportation costs which is further increased by its high water content. The latter is particularly problematic for poplar and willow plantations where the water content at harvest may be above 50%. Up to 20% water loss can be achieved by intermittent harvest and pre-storage which results in a 28% decrease in transportation costs per hectares. Another factor determining transportation costs is the amount of harvested biomass which was examined at 30% water content and 3 different transportation distances (20, 50 and 100 km).

Figures 1-2 show the discounted earnings of the three species using the present value of the expected net cash flow and the investment amounts, the sum of these reflecting the net present value of the investment. The intersections of the curves with axis X show the discounted payback period for each scenario at 7% discount rate.

Scenario S1 with 20 km transportation distance and scenario S2 with 100 km transportation distance are the extremes for all three species, with the net present value of the rest of the scenarios and transportation distances spreading between them.

In high yield scenarios S1 and S4, discounting inflicts no significant change in payback periods, which reduces financial risk. In the 15th year the discounted values in high yield scenarios are around the half, while in low yield scenarios less than the half of the nominal value.

The two figures clearly illustrate the effect of the length of the rotation on the cash flow. In all the three species, it can be stated that within a scenario at the three examined transportation distances by the grater transporting distances caused increasing costs do not cause any differences in the payback times.

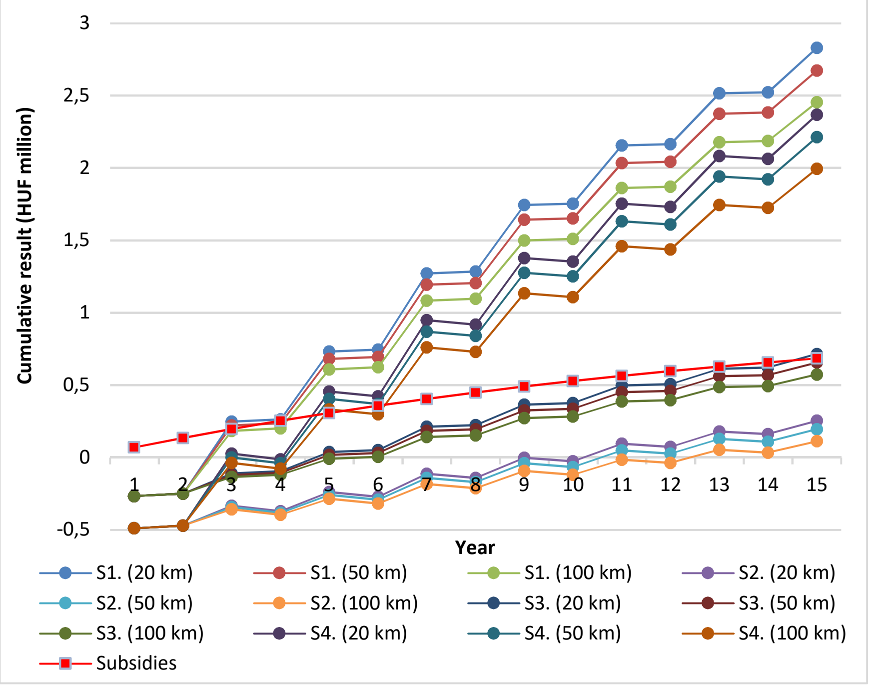

Figure 1: Discounted cumulative earnings of a poplar SRC plantation for 15 years
Source: Own calculations

The discounted return period of 7 years is achieved in three scenarios for all three species: S1 (extensive farming on good quality lands), S3 (extensive farming on low quality lands) and S4 (intensive farming on good quality lands). In scenario S3, in spite of the relatively fast return, NPV in the 15th year is less than 750,000 HUF for all three species (poplar: 656.528 HUF, willow: 739,673 HUF, black locust: 684,777 HUF).

In both figures, the NPV of area payments are shown with a red line, which value is 685,106 HUF in the 15th year. Farmers are entitled to area payments without planting SRC's. Therefore, only those scenarios can be accepted as economically sustainable on the long term whose values are above the area payments. In this case, these are scenarios S1 (extensive farming on good quality lands) and S4 (intensive farming on good quality lands).

For black locust (*Figure 2*), the 5-year rotation and the different production technology may counteract the disadvantage resulting from the lower growth. Thus, although on different lands, black locust plantations can be as successfully utilized as the other two species. The longer rotation, however, results in higher unpredictability of production and financial risks, too. Financial assets are committed for a longer time, and plantation costs can only be returned in every 5th year.

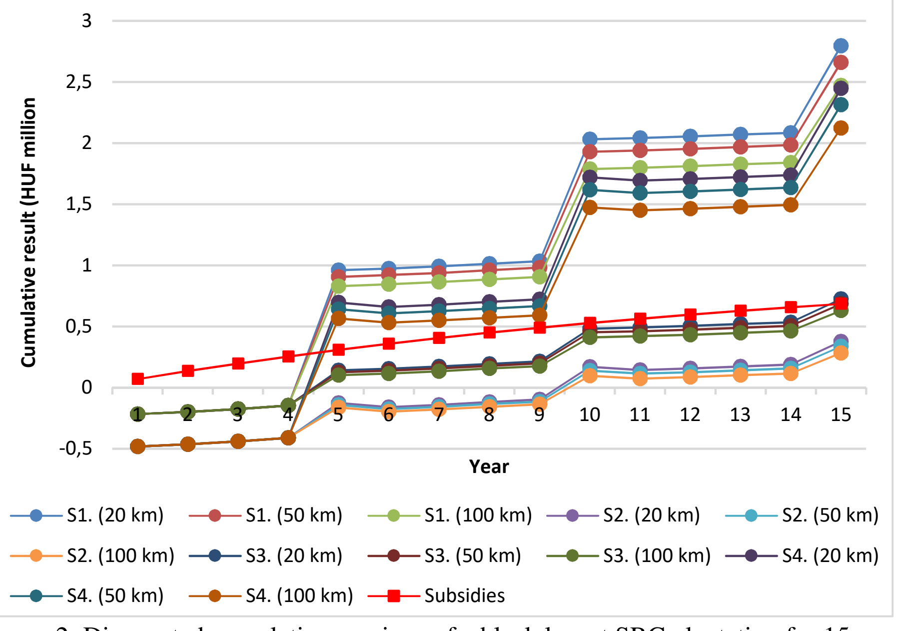

Figure 2: Discounted cumulative earnings of a black locust SRC plantation for 15 years
Source: Own calculations

Intensive farming is the most effective way to achieve an earlier return and to minimalize risks. Even though the biomass yield of SRC plantations is higher than that of traditional forests, it does not mean that SRC's can be sustainably maintained on lands of any quality. Due to their ecological requirements, not all lands unfit for agricultural production are suitable for SRC plantations.

Energy balance of SRC's and doubts about the results

Energy plantations for producing primer biomass are a result of the efforts to increase the use of renewable energy resources. Thus it is necessary to examine the factors influencing sustainability, especially the energy balance. One of these factors is the difference of the energy produced and the energy used for production and utilization; the other factor being the ratio of energy output and input.

The exact energy input is questionable, especially in intensive production, due to the difficulties in calculating the energy used for the manufacture and transportation of fertilizers and pesticides.

Due to the fluctuating yields, the produced energy varies in a wide range. Uncertainty is further increased by the high fluctuations in the water content of woodchip which influences caloric value. In the literature there are significant differences in the caloric values used for energetic calculations. The significant differences (18% and 47%) between the two caloric values used in the current model and the extremes of yield add up, thus increasing the differences. *Table 1* shows the differences between caloric values at 30% and 50% water content. Due to the fact that all factors used for the calculation vary in a wide range, no exact ratios can be determined for the energy balance, only the correlations can be examined. The yield fluctuations and the differences between caloric values are determining factors in judging the energy ratio from the point of view of environmental sustainability.

Table 1: Caloric values of SRC's at 30 and 50% water content

Species	Caloric value at 30% water content (GJ/ha/year)		Caloric value at 50% water content (GJ/ha/year)	
	Unit values		Unit values	
	Lowest: 12,2 MJ/kg	Highest: 14,44 MJ/kg	Lowest: 7,1 MJ/kg	Highest: 10,44 MJ/kg
Poplar	151,3	473,6	123,5	480,2
Willow	173,2	493,9	142,0	501,1
Black locust	103,7	411,5	85,2	417,6

Source: Own calculations, *Széll* 2007, *Lukács* 2011

This fact makes the long term environmental sustainability of biomass production and use questionable. Energy ratio is much more suitable to reflect the production efficiency on the examined plantation using the energy output per energy input.

The energetic metrics (difference and ratio of energy output and input) can be estimated in specific cases but no general conclusions can be drawn for the energy production of SRC primer biomass sector as a whole.

The water content of woodchip affects not only caloric value but transportation costs and carbon dioxide emission as well. Thus it is not sufficient to determine the energy balance/energy ratio of the production but the energetic and technological examination of the whole SRC sector is necessary. The good energy balance of the production may be degraded by the transportation and utilization of high water content woodchip, and besides that, the efficiency level is also fundamentally determined by the method of final utilization.

For electricity-only utilization in power plants used in the model, the conversion efficiency is between 22% and 35%. From the point of view of electricity generation this efficiency means that only one third-one quarter of the energy content of the biomass is utilized. From the point of view of the energy ration of SRC plantation this efficiency means that at least a fourfold energy output is necessary to produce the same amount of (electrical) energy as the fossil energy input used for the production and manipulation of the biomass.

This suggests that the environmentally more sustainable (lower energy ratio) extensive production is questionable on low quality lands where the plantation of SRC's are encouraged by many.

As a counter-argument it can be mentioned that the efficiency of fossil power plants in Hungary is 20% to 75%, depending on the energy source, capacity and technology. Thus, only this proportion of the fossil energy used for biomass production could be transformed into electric energy. Besides that, efficiency improvement by modernizing existing fossil power plants may also be an alternative to building new biomass power plants.

In general it can be concluded that when studying the energy balance of biomass produced for electricity, the electric energy amount produced by the conversion should not be related to the energy content of the biomass but instead, to the total input energy used for the production and manipulation of the biomass.

From the point of view of environmental sustainability it must be emphasized that among the purchase criteria of power plants there are no regulations about environmental sustainability and harmful emissions. Transportation being not the responsibility of the power plant, the energy balance degradation and excess carbon dioxide emission derived from transportation is difficult to control.

CONCLUSIONS

The production technology of short rotation coppice (SRC) is an attempt to make a normally extensive sylviculture work in an intensive production system while meeting the requirements of economical and environmental sustainability at the same time. SRC attempts to satisfy an ever increasing, almost infinite electricity requirement by a system with land and biological limits. The unpredictability is further increased by the fact that meeting a physical demand like the electricity requirement by biological systems presents a risk of exposure to abiotic and biotic factors as well.

The relatively high investment costs and the intensive production technology result in a pressure for high output in order to shorten return time and to keep risk factors at the minimum. One of the two directions aims at higher output by exploiting maximum growth potential using shorter rotation periods. In this case rotation periods are determined by the proportion of yearly yield compared to the actual average yield. The other direction prefers longer rotation periods due to the high costs of harvest. The difference between these two directions is reflected in the analysis of economical models of willow and poplar SRC's with short rotation periods and higher growth potential versus black locust SRC's with 5-year rotation periods and lower growth potential. Longer rotation can compensate for the lower yearly yield of the coppice.

The difference between intensive and extensive production is significant from both economical and environmental points of view. Farmers are generally interested in intensive production in order to achieve high and balanced yields while exploiting maximum growth potentials. SRC's are recommended for lands unfit for agricultural production, however, on these lands the extra input of intensive production, the biological potential of special breeds cannot be efficiently exploited due to land conditions. On these lands extensive farming should be considered using specially selected breeds. In the literature a wide range of yield figures can be found but efficient production can only be achieved at the highest yield values. Lower yields can be compensated by cost optimization for a limited time but the cumulative outputs of the model show that profit can only be generated with high yields. So, farmers should strain after yield maximization which can be achieved either by intensive production or on better lands even by extensive farming, too. For environmental sustainability the highest possible energy ratio should be desirable which can be achieved on good lands and by extensive farming. Good quality lands can be excluded from the scenarios for favourable environmental sustainability as SRC's are justified only on lands unfit for agricultural production. As shown above, intensive farming is not always economically sustainable on low quality lands, and due to the extra input its energy ratio is also lower than the desired level for environmental sustainability. In intensive production, the yield increase from extra input reduces the energy ratio. As a result, return will be uncertain and the extra input will not be profitable from an energetical point of view. On low quality lands, extensive production can be environmentally sustainable but the probable low yields make it economically unsustainable. From the established model it can be concluded that SRC's can meet the requirement of either economical or environmental sustainability but not both at the same time. Although extra inputs (may) result in higher yields but the energy ratio will still decrease.

The use of biomass is an often reasoned with the statement that burning biomass is carbon dioxide neutral, for only as much carbon dioxide is produced during burning as much the plants absorbed during their lifetime. In our opinion this is only partially true as producing and manipulating biomass is done using fossil fuels. Thanks to biological productivity the input energy is multiplied, from which some can be used during utilization. In our opinion, this would be the correct statement: the utilizable energy during biomass burning should be more than the fossil energy used for the production and manipulation of biomass products. Biomass being a conditionally renewable resource, fossil energy must be used every year for biomass production. As a conditionally renewable resource, the return of the yearly inputs poses both financial and energetical risks due to the unpredictable production. This presents a competitive disadvantage against traditional renewable resources.

The conversion efficiency of biomass based electricity generation is not expected to improve in the near future as opposed to solar and wind energy production, which are based on physical not biological grounds and they need no lands for the production. This may result in conditionally renewable resources, including primer biomass production being sidelined on the long term. As opposed to the high material cost of biomass based electricity generation, solar and wind energy production has a high initial investment requirement but low yearly maintenance cost. With biomass production, first-cost depends on the variable yield, and besides that, production costs depend on the price of fossil fuels which make this branch difficult to plan from both economical and environmental points of view.

As described above due to the conversion efficiency and difficult production plannability the biomass is much more recommended to use for heat generation in small decentralized plants as highlighted by lots of authors as well. The environmental-economic-social sustainability depends on lots of interrelated factors, as biomass use is much more complicated due to the biological bases which results in the uncertainties in the sector that is emphasized in the literature and in our model as well.

For grants and investments for renewable resources not only the economical but also environmental sustainability should be examined including constant traceability for the whole product line. Currently only the emission of power plants is controlled but the production and transportation of biomass are not.

A rövid vágásfordulójú, sarjaztatásos ültetvények fenntarthatósági vizsgálata

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A dolgozat fő célkitűzése a nyár, fűz és akác fafajokból álló rövid vágásfordulójú, sarjaztatásos ültetvények gazdasági és környezeti fenntarthatóságának meghatározása. Mindhárom esetben egy intenzív és egy extenzív művelési módot tüntettünk fel, a kétféle technológiához tartozó eltérő költségszínvonallal együtt. Az így kapott termelési költségek és termelési értékek szélsőértékeinek felhasználásával állítottuk fel a négy forgatókönyvet, amelyekhez termőhelyi adottságokat is rendeltünk.

Az évenként jelentkező ráfordításigény miatt feltételesen megújuló energiaforrásnak is nevezett biomassza termelése a kiszámíthatatlanság következtében mind pénzügyi, mind energetikai kockázatot jelent. A biológiai potenciál minél magasabb fokú kihasználása mellett a gyors megtérülés és a gazdaságilag fenntartható gazdálkodás a kedvező adottságú termőterületen, elsősorban intenzív termesztéstechnológia alkalmazása mellett érhető el. Ezek a feltételek a létesíteni tervezett, szántóföldi növénytermesztésre alkalmatlan területeken nem teljesülnek.

Az energetikai vizsgálatok is rávilágítanak az egész energetikai célú biomassza-hasznosítás körül tapasztalható bizonytalanságra. A használatos energetikai mutatószámok, az energiahányados és a befektetett és a megtermelt energia különbsége ugyan konkrét esetekben megbecsülhető, de nem lehet a környezeti fenntarthatósággal kapcsolatos általános érvényű következtetéseket levonni.

A felállított modell segítségével megállapítottuk, hogy melyik forgatókönyv esetében folytatható gazdaságilag fenntartható biomassza termelés, és milyen esetekben érvényesül a környezeti fenntarthatóság szempontja. Kijelenthető, hogy rövid vágásfordulójú, sarjaztatásos energetikai ültetvények külön-külön megfelelhetnek a gazdasági és a környezeti fenntarthatóság kritériumainak, de mindkettőnek egyszerre nem.

Kulcsszavak: megújuló energiaforrás, biomassza-hasznosítás, megtérülési idő, energiaegyenleg

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